

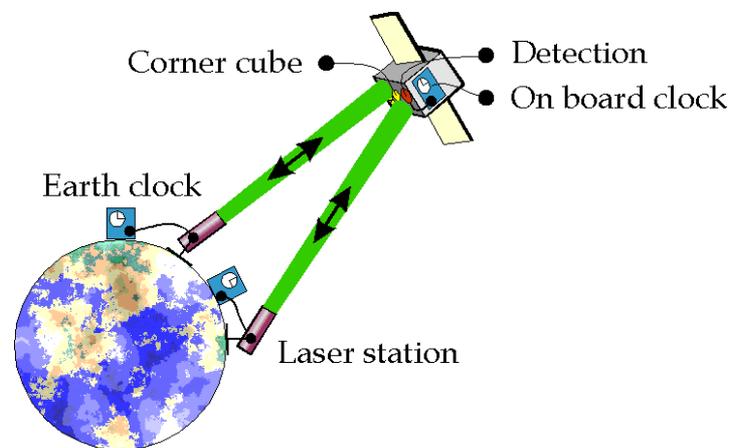
## The Time Transfer by Laser Link (T2L2) experiment

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### Introduction

The T2L2 experiment should allow the synchronization of remote clocks on Earth and the monitoring of a satellite clock with a time stability of the order of 1 ps over 1000 s and an accuracy in the range of 100 ps. The principle is based on the propagation of light pulses between the clocks to synchronise as in the LASSO Experiment [1,2] but without any external calibration [3] (Figure 1).

A clock and a detection timing system on board a satellite are used as a relay between remote ground clocks. Each ground clock to be synchronized is connected with a laser station. The offset between the ground clocks can be accurately determined, that is to



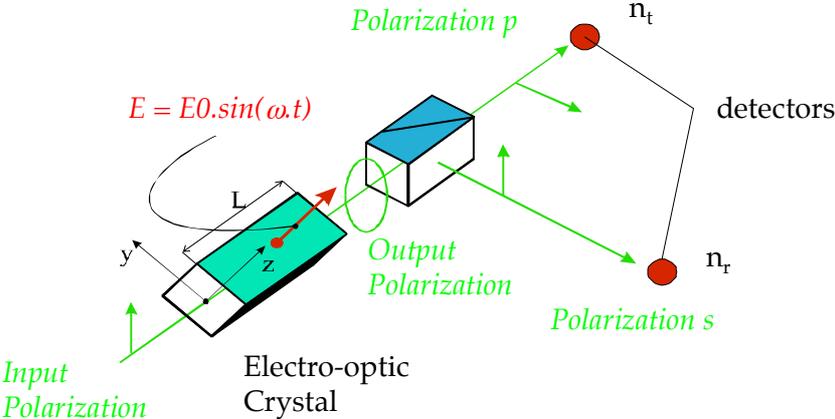
**Figure 1 : T2L2 Principle**

say the phase difference between the 10 MHz signals of the clocks can be measured, if the ground start times are measured accurately. These accurate measurements are obtained with the optical timer described in the following [4,5]. T2L2 has been accepted by the European Space Agency in the frame of the ACES (Atomic Clock Ensemble in Space) Project [6]. The ACES project will gather on board of the International Space Station a cold atomic clock [7], a H-Maser a microwave link and the optical link T2L2. Some new optical timers, a new design of the optical space segment and the definition of a new time origin allow direct accurate time transfer without external time calibration. T2L2 should be able to measure the performances of ground clocks having a stability in the range of  $3 \cdot 10^{-15}$  over the station visibility period (around 200 s). One can also accumulate the data of several successive passages of ISS to reach a stability in the  $3 \cdot 10^{-17}$  range over ten days. A real

simulation of the T2L2 experiment was done at OCA between the Lunar Laser ranging and the Ultra-mobile station via a prototype of the T2L2 space segment.

**Optical statistical timer**

The standard method to time a light pulse is to transform it into a voltage pulse via a photodiode [8]. The delay of an electrical pulse with respect to the light pulse depends on many parameters which cannot be safely assigned. An other uncertain delay is introduced by the electronic device allowing the comparison between the electric pulse and the clock reference. Finally the timing uncertainty is of the order of the nanosecond. The goal of the optical statistical timer is to reduce this uncertainty to reach the 50 ps range. The optical timer principle [5] is to pass the light



**Figure 2 : Optical Statistical Timer principle**

pulse through an electro-optic crystal excited by an oscillating electric field (figure 2). Depending on the light pulse arrival time into the crystal the polarization of the latter is more or less changed. Conversely, analysing the polarization allows to deduce the arrival time. By synchronizing the electric field oscillation with the oscillating voltage delivered by the clock, one obtains accurate datation. The output polarization is analysed by separating the horizontal polarization from the vertical one and by measuring the amount of photon in each polarization for a given light pulse. The error on the photon number ratio, due to the photon statistic, limits the precision of the timer. Numerically, with a frequency excitation of 500 MHz the photon statistic will involve a timing repeatability error of 5 ps if the light pulse number is 10 000. Some experiments leaded with a 500 MHz clock signal permitted to obtain a repeatability error in the 10 ps range. The actual objective is to build an optical timer able to work with a 10 MHz signal. It will be then possible, by using

directly the 10 MHz output of a standard clock, to obtain accurate timing with respect to this 10 MHz reference signal. In the T2L2 frame, an accurate time transfer in the range of 60 ps is expected.

### The T2L2 Ground experiment

To measure the T2L2 performances, an experiment has been led at OCA between the Lunar laser Ranging (LLR) and the French Transportable Laser Ranging System (FTLRS) via a prototype of the on-board T2L2 space equipment (figure 3). This experiment was designed to measure the time stability and the repeatability error of the optical time transfer and to evaluate the correlation between the time transfer and the satellite-stations distances. The time accuracy will be studied in a future experiment. The laser stations were a few meters apart and linked with the same ground clock. The T2L2 prototype was put on the top of the Calern mountain at 2.5 km from the laser stations. The T2L2 prototype was made up of a corner cube, a mono-mode optical fiber, an input optic, a fast photo detector, a derivative filter, an electronic timer, a quartz cristal oscillator, a computer, and a power supply (figure

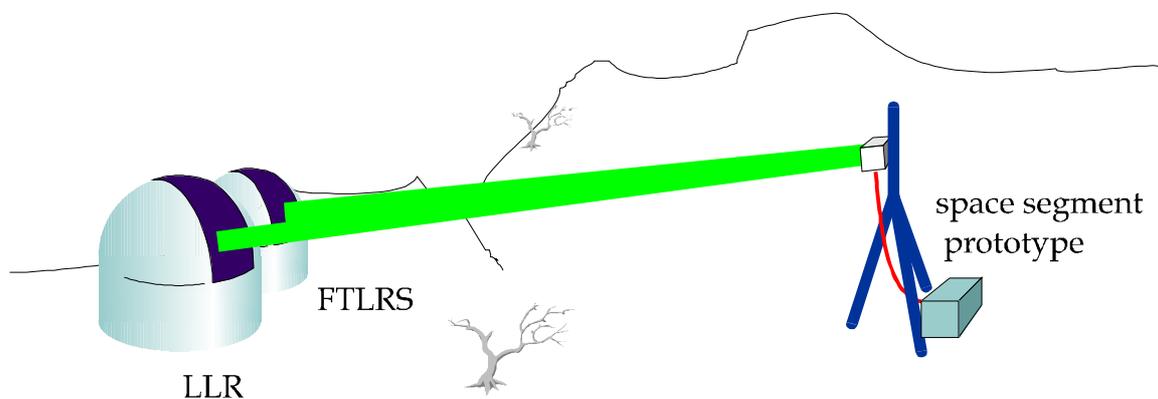
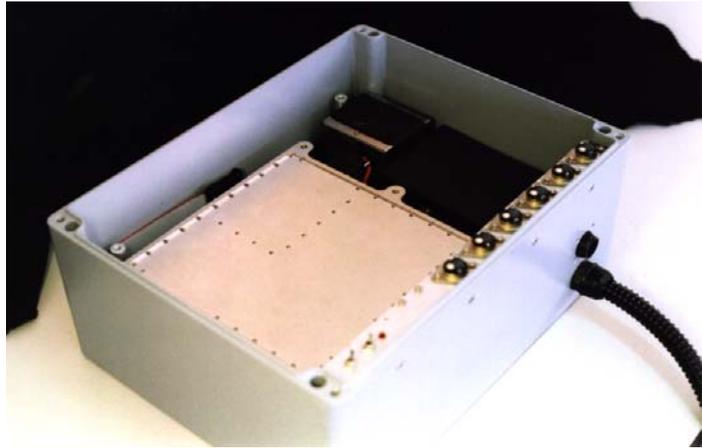


Figure 3 : T2L2 Ground Experiment

4). An optical box, gathering the input optic and the corner cube, was placed on a mast. The rest of the equipment was located on the floor in a metallic box. The photo detector, the derivative filter and the electronic timer was designed by Dassault Electronique. The T2L2 prototype time reference was a LCEP Quartz having a time stability in the range of  $5 \cdot 10^{-13}$  over 10 s. The T2L2 ground equipment for the FTLRS station (it was almost the same for the LLR station) was made up of a start detector, a return detector, two electronic timers (a Dassault Electronique timer and the

electronic vernier of the optical statistical timer) a YAG laser and a telescope. This timing equipment for both the LLR and FTLRS stations was designed for the T2L2 objective. The ground time reference of the laser stations was extracted from an unique HP 5071A clock in order to eliminate the noise coming from the clock.



**Figure 4 : Space segment prototype**

The measurements have been done in June 98 during more than 10 days. The repeatability error of the echoes obtain with the laser stations was below than 40 ps in a single photon mode and the time stability of the echoes was better than 1 ps over 1000 s. The T2L2 prototype time stability was in the 0.2 ps range over 1000 s. The performances of the time transfer between the ground clock and the T2L2 prototype clock are not yet extracted from the data but the quality of both the ground equipment and the T2L2 prototype equipment allow us to envision some time stability in the ps range. This performance would be a progress of two orders of magnitude with respect to the actual time transfer performances.

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<sup>1</sup> Fridelance P., Veillet C., *Metrologia*, 1995, **32**, 27-33.

<sup>2</sup> Fridelance P., Thèse de doctorat de Physique de l'Université Paris 6, 1994.

<sup>3</sup> Samain E., Fridelance P., *Time Transfer by Laser Link (T2L2) experiment on MIR*, *Metrologia* 1998, **35**, 151-159

<sup>4</sup> Samain E., *Le Laser Lune Millimétrique et nouvelles méthodes de datation*, Thèse de doctorat de l'Université de Nice-Sophia Antipolis, 1995.

<sup>5</sup> Samain E., *Optical statistical timer*, to be published in *IEEE Transactions on Instrumentation and Measurements*, 1998.

<sup>6</sup> Lemonde P., Laurent Ph., Simon E., Santarelli G., Clairon A., Dimarcq N., Audoin C., Petit P., Bernier L., Busca G., Samain E., Salomon C., *Atomic Clock Ensemble in Space on board the Space Station*, this proceedings.

<sup>7</sup> Salomon C., Lemonde P., Laurent P., Simon E., Santarelli G., Clairon A., Dimarcq N., Petit P., Audoin C., Gonzalez F., Jamin Changeart F., In *Proc. ESA Symposium on the utilisation of the Space Station*, 1996, 289-294.

<sup>8</sup> Samain E., *Timing of optical pulses by a photodiode in Geiger mode*, *Applied Optics*, 1997, **37**, No 3, 502-506.